Properties of Wide BandGap Materials

INTRODUCTION

Future Radar Design Requires Higher Power RF Amplifiers

Surface Navy Radar

Aperture size constraints:
S-band: 32 m^2
X-band: 10 m^2

- NAVY REQUIREMENTS FOR LONGER RANGE DETECTION, DISCRIMINATION & COUNTERMEASURES CHALLENGE FUTURE RADAR DESIGNS.
- NAVAL ARCHITECTURE LIMITS ANTENNA APERTURE SIZE.
  - $\Rightarrow$ REQUIRE **HIGHER POWER RF AMPLIFIERS**
- CANNOT BE PROVIDED BY CURRENT GaAs TECHNOLOGY.
- NEW HIGH POWER AMPLIFIER TECHNOLOGIES NEEDED TO MEET FUTURE NAVY REQUIREMENTS.
- THESE REQUIREMENTS CAN ONLY BE MET USING **WIDE BANDGAP POWER AMPLIFIERS.**

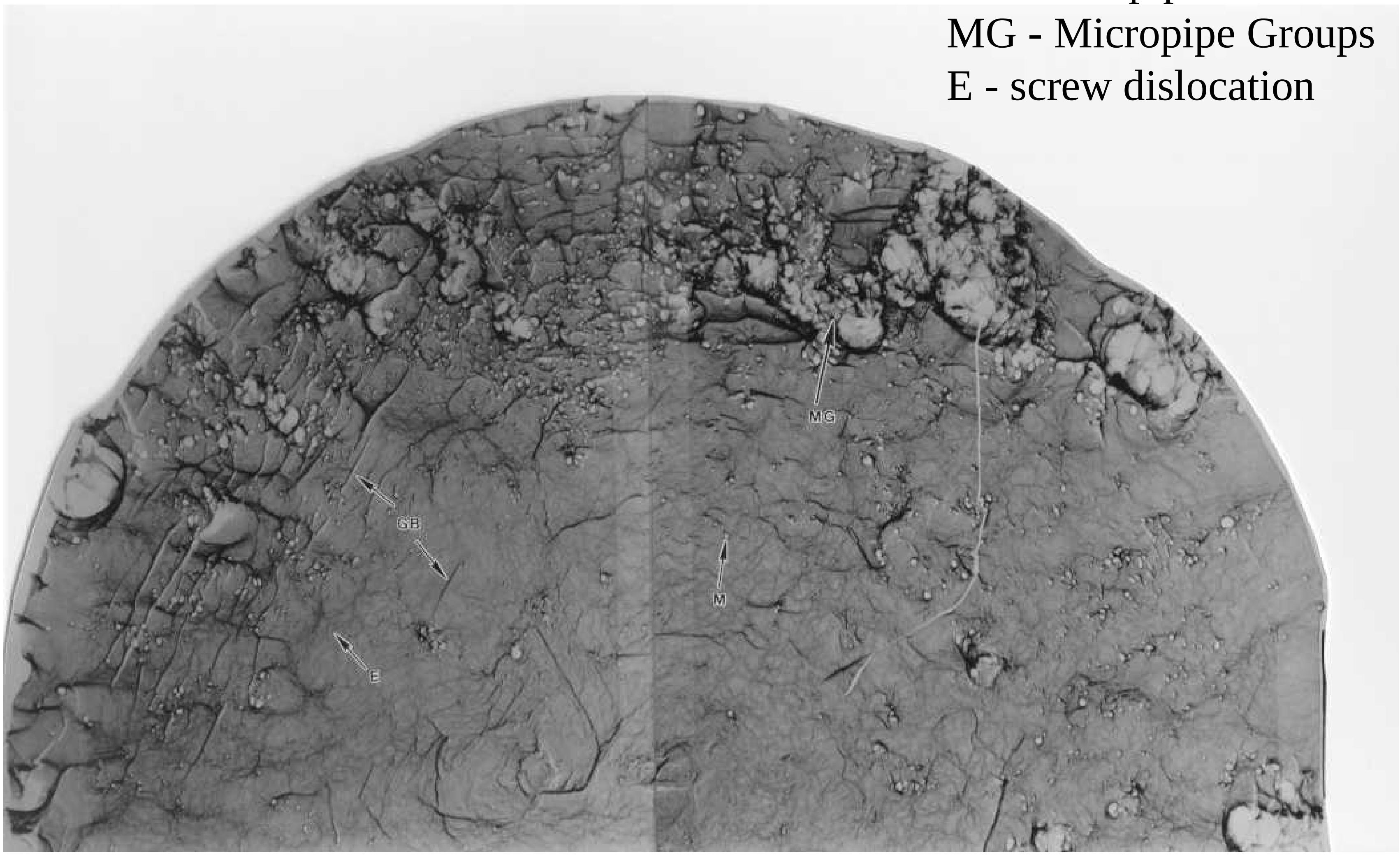
Background

- Large-area GaN and SiC substrates required for next-generation high power/high frequency applications (e.g., RF power amplifiers) in critical Navy systems.
    - 2-3″ SiC wafers commercially available.
    - 4″ SiC wafers under development.
    - 2″ GaN wafers under development.
- <u>Structural defects</u> (dislocations, micropipes, etc.), <u>lattice imperfections</u> (vacancies, interstitials, antisites), <u>residual impurities</u> (Si, O, C, B, N, etc.), and <u>dopants</u> (Si, Mg, V, etc.) play significant roles in **electronic properties** of wide bandgap semiconductors.
- Need to develop contactless methods to screen/assess wafers for crystalline quality and conductivity-type in a production line environment.

Structural Characterization

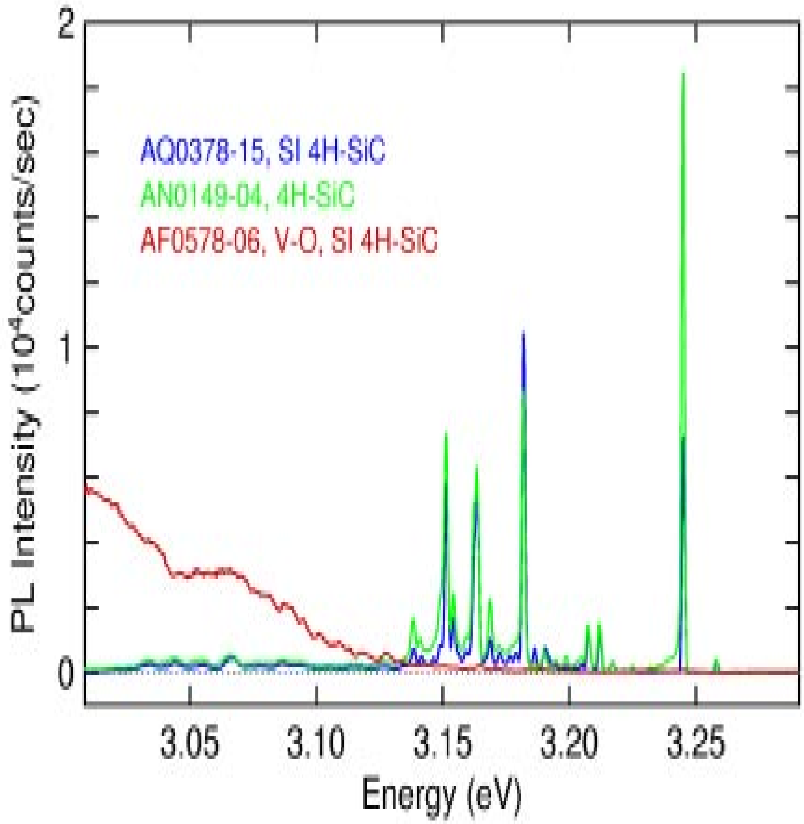
X-ray Topograph (M. Dudley, SUNY Stony Brook)

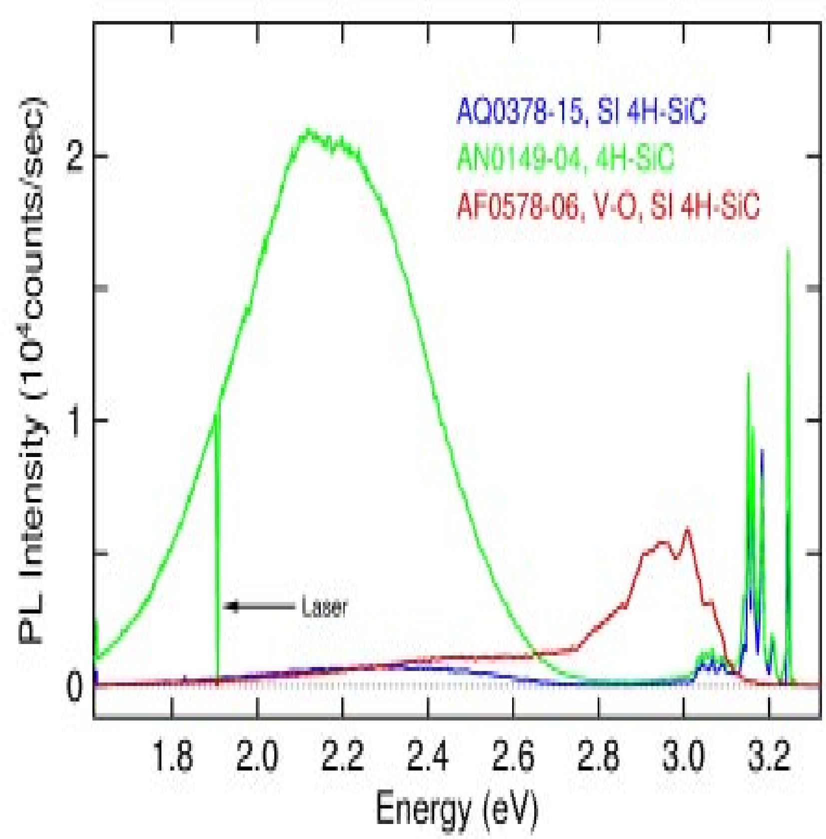
GB - Grain Boundary
M - Micropipe
MG - Micropipe Groups
E - screw dislocation



SiC PROPERTIES

Low Temperature Photoluminescence

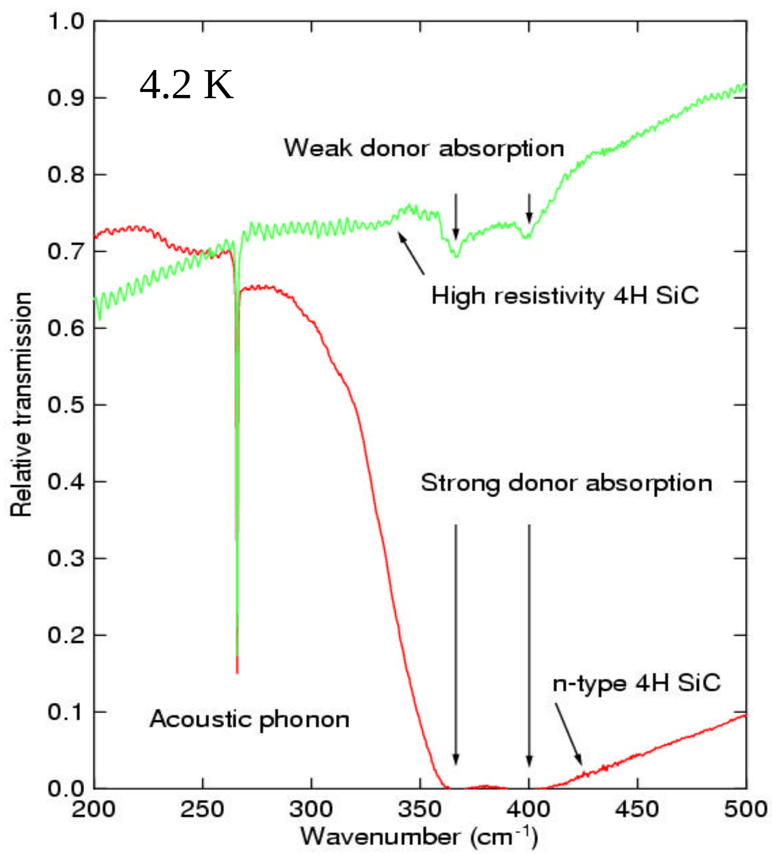


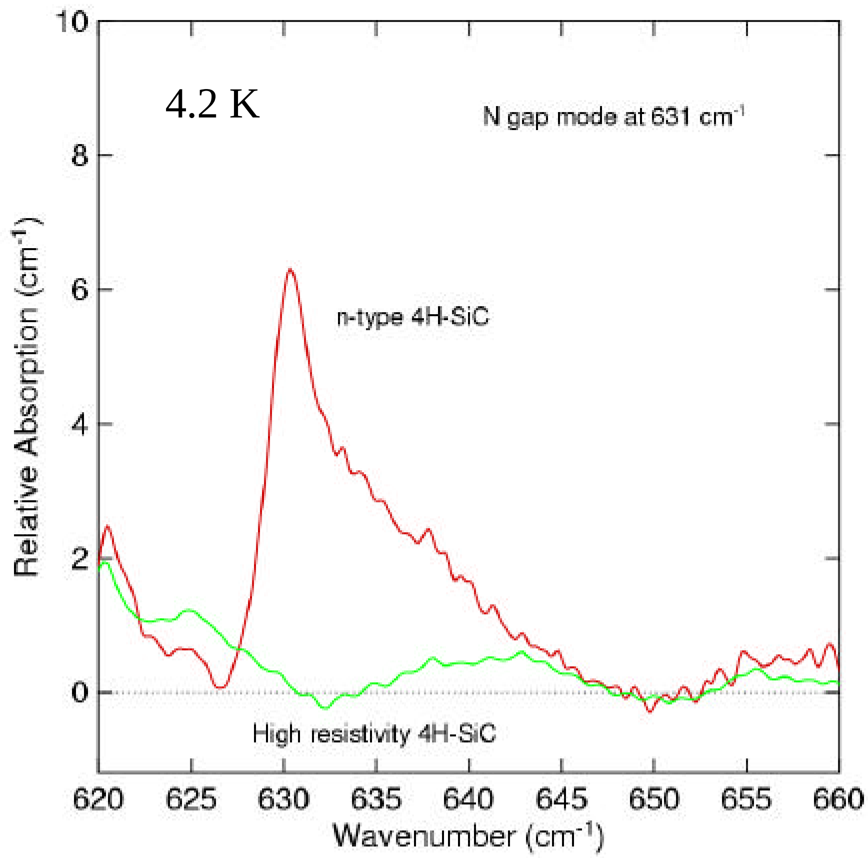


- Emission near 3.2 eV due to N-bound excitons.
  - Narrow linewidths reflect high crystallinity of samples.
- Strong for n-type and undoped (SI) samples; weak for V-doped sample.

- Different deep emission bands.
  - Strong band near 2.2 eV from n-type sample (green).
  - Weak band near 2.3 eV from undoped (SI) sample (blue).
  - Strong structured band from V-doped sample (red).

Non-destructive Infrared Assessment of Impurities

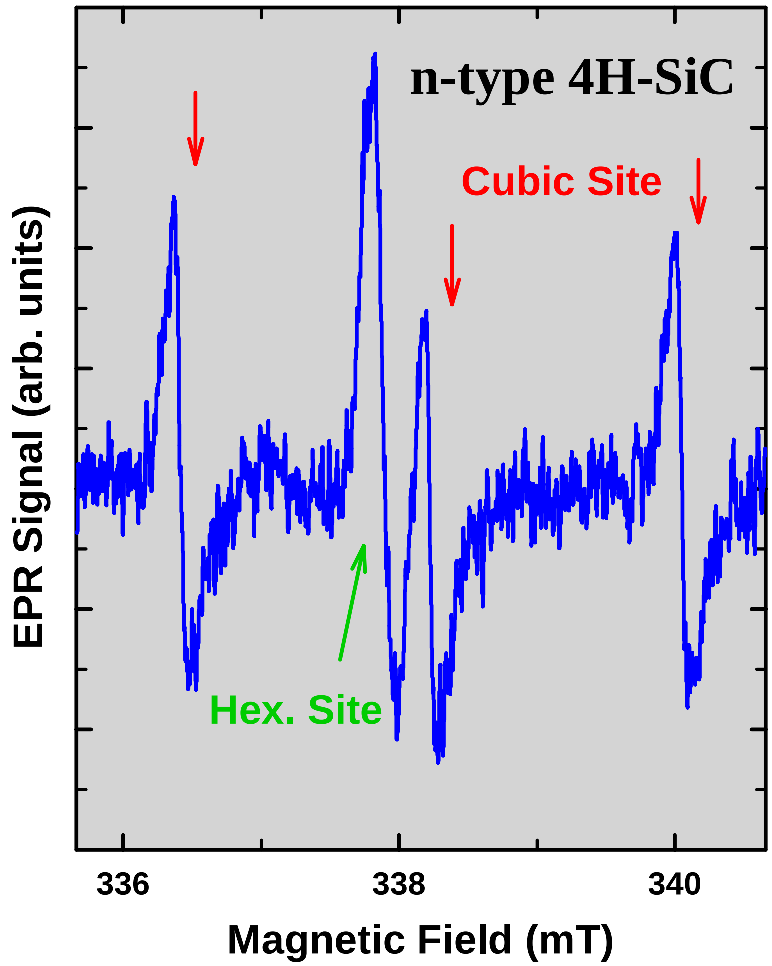


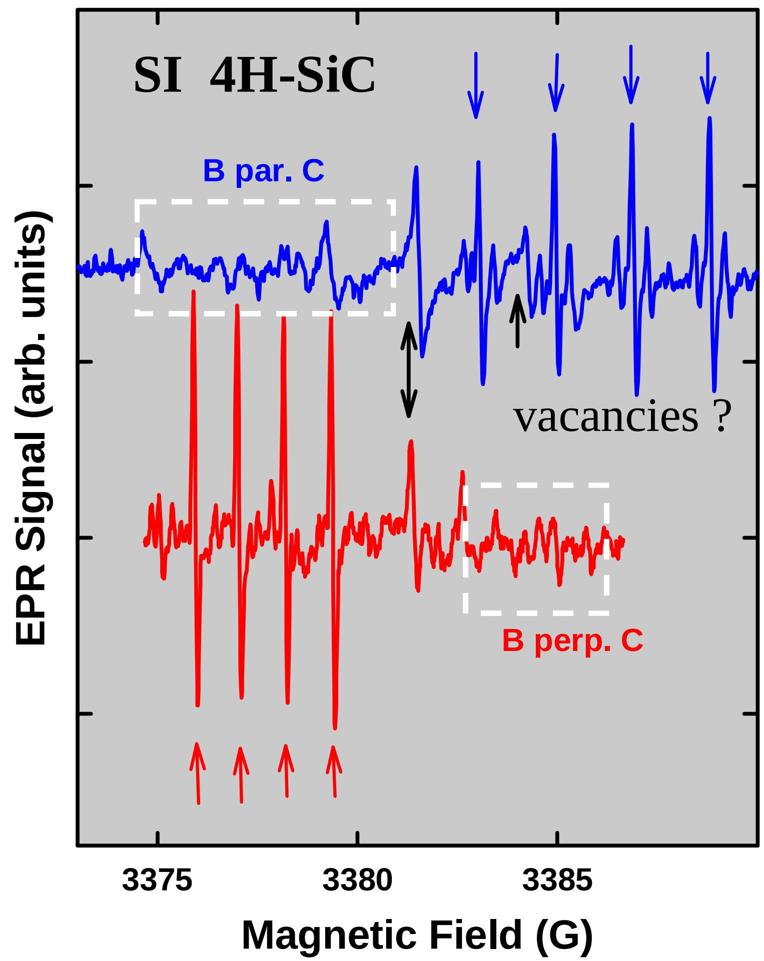


- n-type sample absorbs strongly in region of 1s-2p (N donor) electronic excitation transitions.
- High-resistivity sample absorbs only weakly.

- Feature near 631 cm^{-1} due to N localized gap mode.
  - intensity proportional to N concentration on C site.
  - work underway to obtain calibration standard.

Electron Paramagnetic Resonance (EPR)



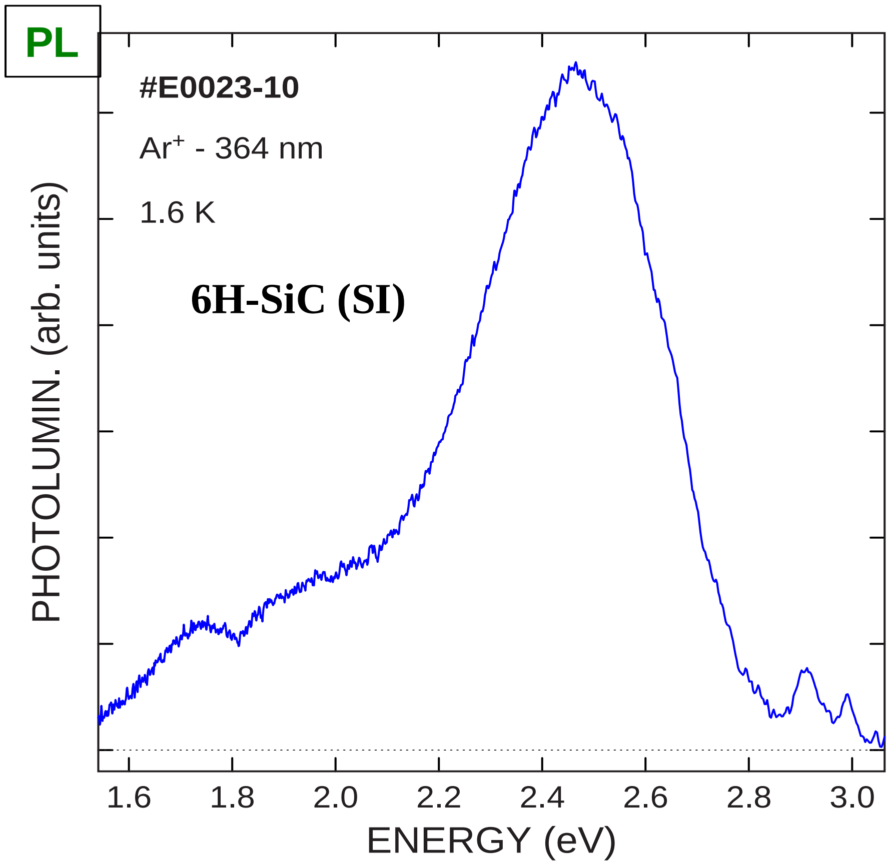


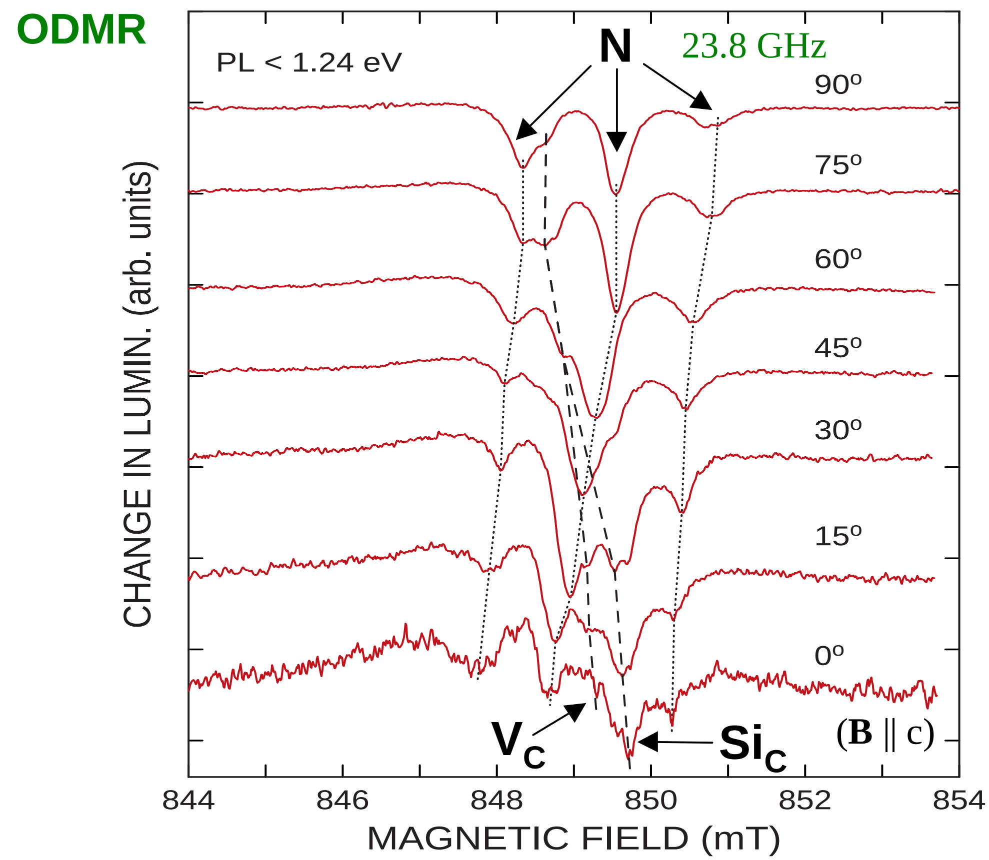
- "Fingerprint" 3-line spectrum of N observed (s=1/2, I=1).
- $N_c = 2.2 \times 10^{17}$ cm^{-3}; $N_h = 1.4 \times 10^{17}$ cm^{-3}.

- Residual shallow Boron acceptors.
  - Hexagonal site indicated by quartets of arrows (I=3/2); $B_h \sim 2.2 \times 10^{14}$ cm^{-3}.
  - Cubic site (weak) indicated by dashed rectangles.

W.E. Carlos – Code 6860)

PL/ODMR of Large-Area SiC Substrates



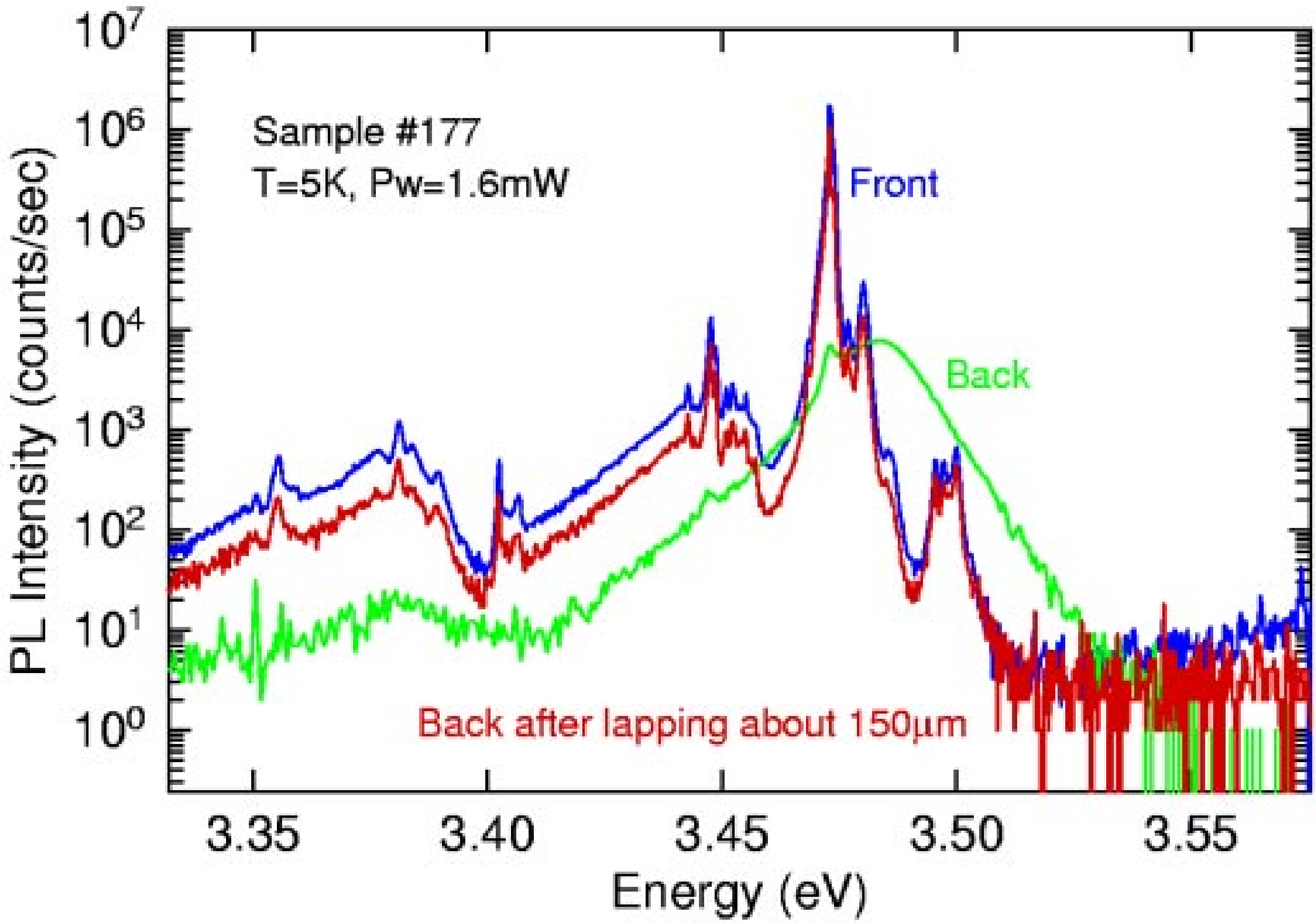


- **ODMR**: Combines PL + EPR - - probes optically-excited states.
- Broad PL band observed at 2.4 eV (weak PL < 2.0 eV) from SI 6H-SiC.

- Three defects identified in as-grown wafer.
  - N donors on hex. + two cubic sites.
  - C vacancies + Si_C anti-sites (as reported from EPR of e^--irradiated 6H-SiC).

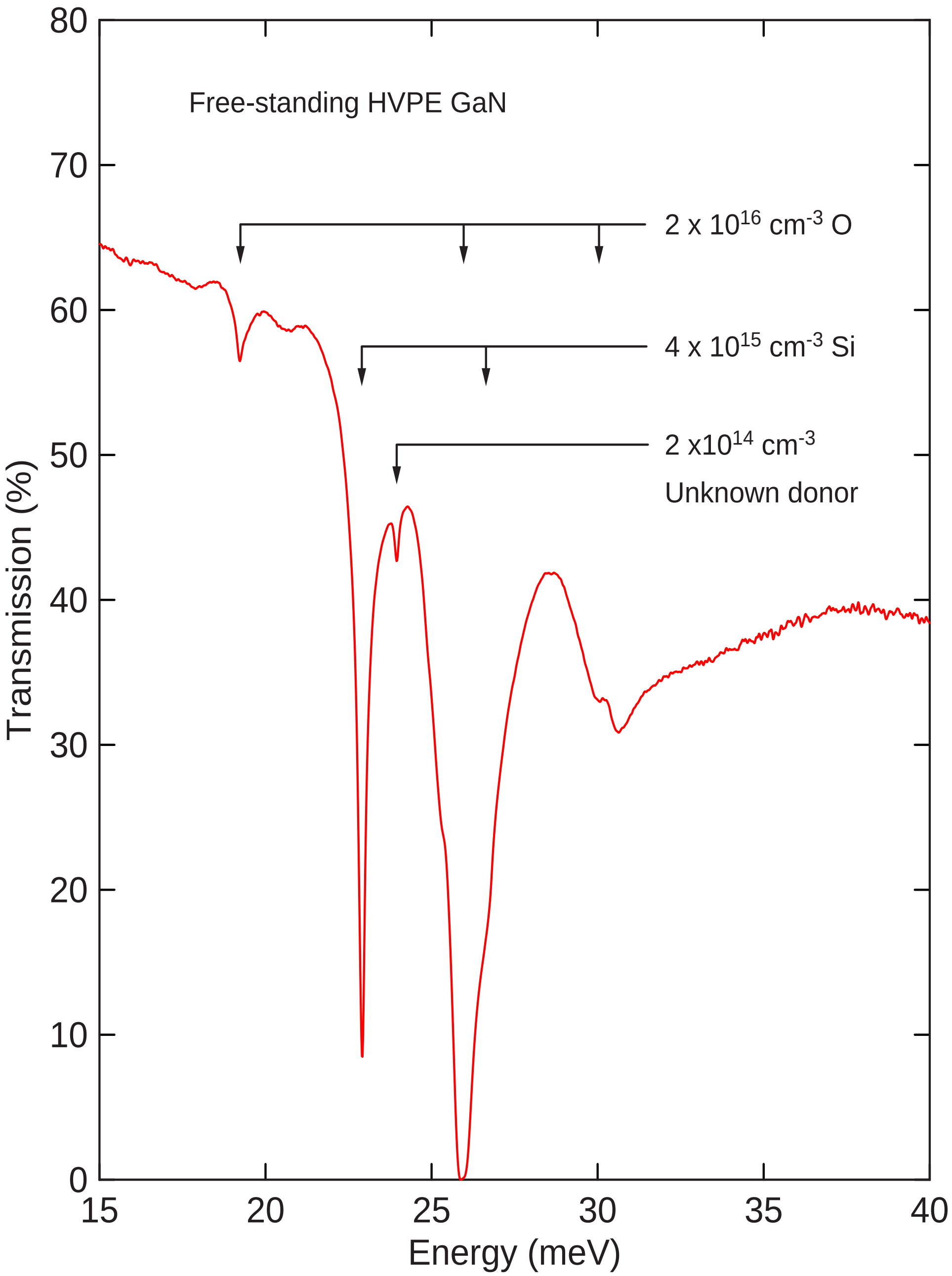
GaN PROPERTIES

High-Resolution PL of Free-Standing HVPE GaN



- Very sharp bandedge emission due to free and impurity-bound excitons observed at low temperature.
- Material exhibits highest room-temperature electron mobilities (~ 1350 cm^2/V-sec) reported to date.

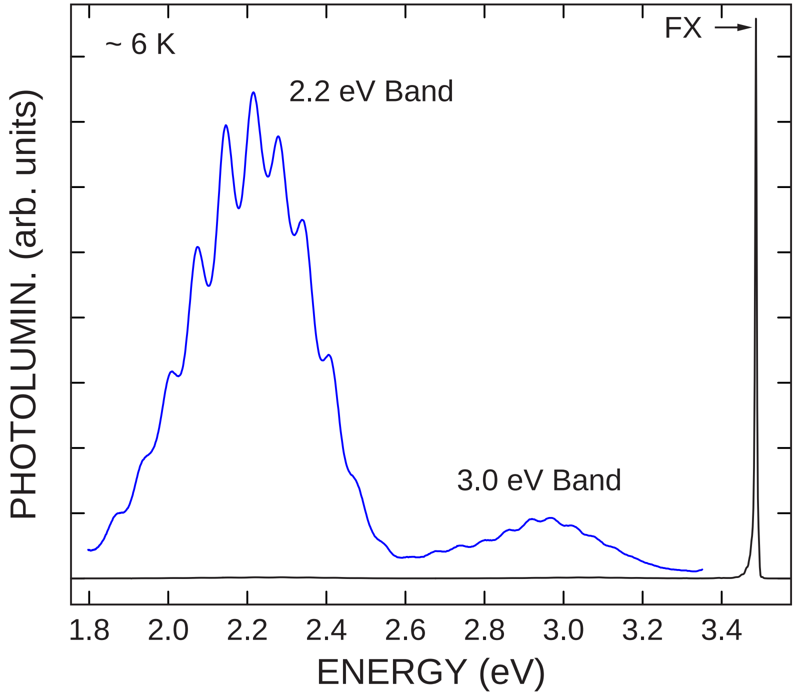
Non-destructive Infrared Assessment of Impurities



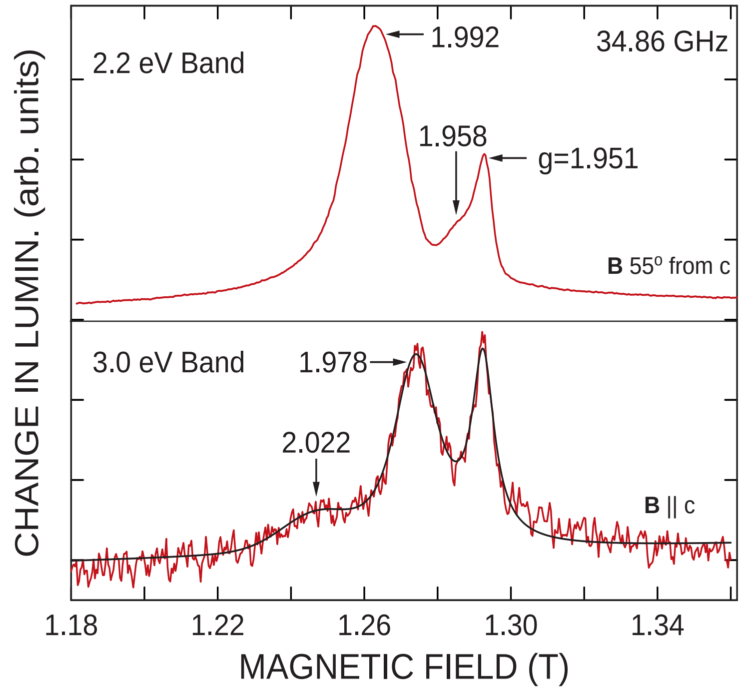
- Donors and acceptors in semiconductors have characteristic optical absorption signatures.
- Spectral position is unique to a specific impurity and absorption intensity is proportional to concentration.
- Absorption features in the IR transmission plot are due to <u>three</u> donors.

Optically-Detected Magnetic Resonance of High-Resistivity GaN

PL



ODMR



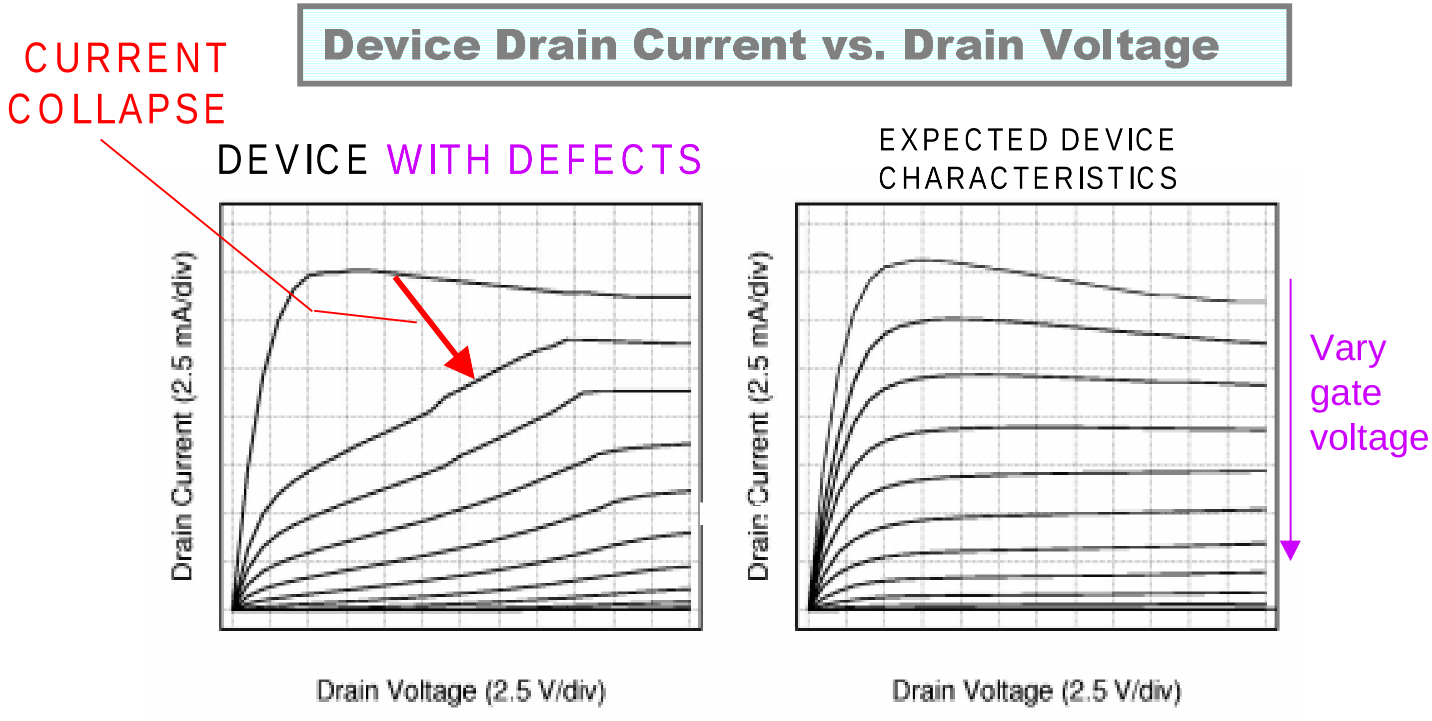
- In addition to sharp band-edge emission (FX), two broad PL bands at 2.2 and 3.0 eV ("optical signature") are observed from HR GaN.

- ODMR reveals that shallow donors (g=1.951) are active in both 2.2 and 3.0 eV bands.
- Four additional defects (g=1.958, 1.978, 1.992, and 2.022) attributed to residual donors and acceptors are also found.

PHOTOIONIZATION SPECTROSCOPY OF DEFECTS IN WIDE BANDGAP ELECTRONIC DEVICES

CURRENT COLLAPSE IN WIDE BANDGAP DEVICES

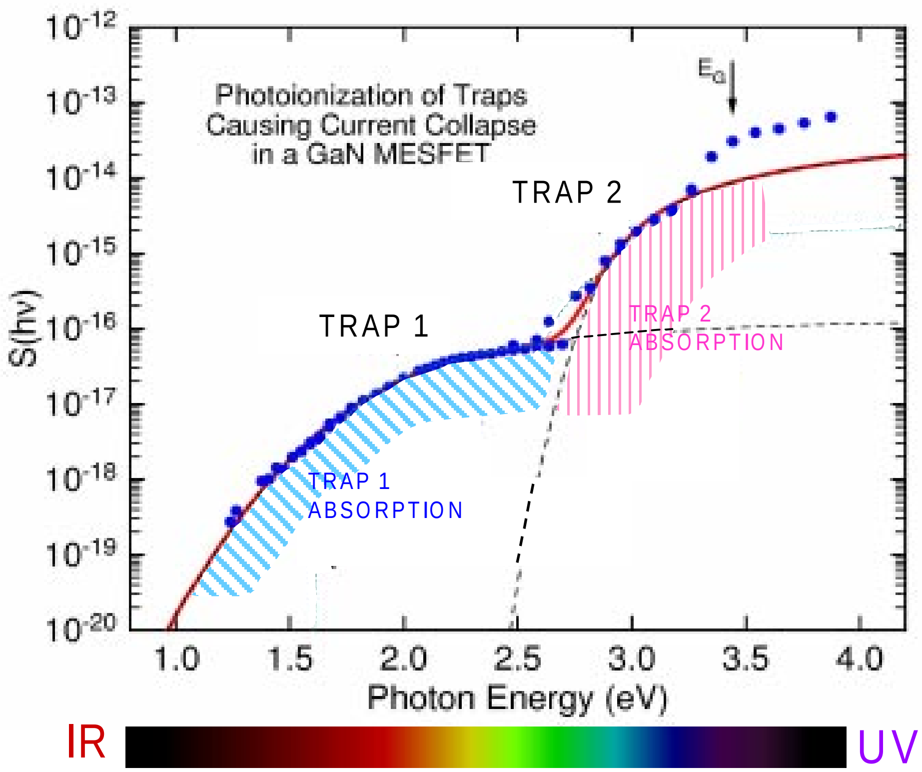
- SOME DEVICES EXHIBIT OUTPUT DEGRADATION AFTER TURN-ON.
  - Due to MATERIAL DEFECTS.
- DEFECTS CAUSE **"Current Collapse".**
  - Defect **traps** mobile charge carrier - **reduces device current & power.**



- **LIGHT** WILL FREE (PHOTOIONIZE) CARRIERS FROM TRAPS AND **RESTORES DEVICE PROPERTIES.**
- ⇒ USE LIGHT ABSORPTION PROPERTIES OF DEFECTS TO **IDENTIFY** & **QUANTIFY** DEFECTS.

Photoionization Spectroscopy of Defects (Traps)

- NEW technique developed at NRL
  - o Dependence of defect light absorption on wavelength (color).
  - o Spectrum determines **unique fingerprint of each defect.**
  - o Provides method to determine **concentrations of defects**.
  - o Leads to method of **defect identification.**
  - o Essential information for defect **elimination.**



Defect Identification from Photoionization Spectroscopy

- Defect incorporation affected by material growth conditions.
- Variation of Trap1 & Trap2 concentrations with material growth pressure:
  - Concentration of Trap2 TRACKS concentration of **CARBON**.
    - **Trap2 is carbon-related defect**.
    - Reduction of carbon expected to reduce this effect.
  - Trap1 concentration varies similar to **structural defects.**
    - Current studies probing this relationship.